Draft

TGP Performance Measures for the Mica Water Use Plan
A Derivation Summary

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Introduction

The Hugh L. Keenleyside (HLK) Dam on the Columbia River near Castlegar, B.C. is known to produce Total Gas Pressures (TGP) that exceed the B.C. Water Quality Guideline for Dissolved Gas Supersaturation (DGS – Fidler and Miller 1997, Aspen Applied Sciences Ltd. 1995, 1997, 1998). Elevated TGP often leads to a condition in fish known as Gas Bubble Trauma (GBT). Acute signs of GBT include bubble formation in the cardiovascular system and organs while chronic signs may include emphysema of external skin surfaces and overinflation of the swim bladder in juvenile or small fish (Weitkamp and Katz 1980, Fidler and Miller 1997). To address this issue in the Mica Water Use Planning Process, B.C. Hydro (the operator of the HLK Dam) has requested Aspen Applied Sciences Ltd. to develop a performance measure for TGP that can be used to compare various HLK Dam operational options that may reduce Columbia River TGP.

With the recent completion of the Arrow Lakes Generating Station (ALGS), the operations of the HLK Dam become somewhat complicated because they are integrally tied to the power production requirements of the ALGS (Operated by the Columbia Power Corporation). Furthermore, because the water discharged from the HLK Dam mixes with the ALGS discharges a short distance downstream from the HLK Dam, Columbia River TGP is the result of the mixed flow resulting from the combined operations of the two facilities. Thus, a descriptive TGP Performance Measure must reflect the operations of not only the HLK Dam but also the combined operations of both facilities.

In past efforts to define the TGP performance of the HLK Dam and the combined TGP performance of the HLK Dam and ALGS Powerplant, TGP alone was used as the performance measure (Aspen Applied Sciences Ltd. 1997, 1998). In this approach, the TGP resulting from operations at the HLK Dam were predicted using the HLK/TGP/GBT Computer Model developed by Aspen Applied Sciences Ltd. (1995, 1996). The model predicts Columbia River TGP for any operation scenario that can be implemented at the HKL Dam. A set of restrictions defined by B.C. Hydro in a Local Operating Order (LOO) prevents the dam operations from entering regimes that can cause structural damage to the dam. The LOO is incorporated into the HLK/TGP/GBT computer model. A further refinement in the model is that a user option allows the operating configuration of the HLK Dam to be set automatically to minimize river TGP while abiding with the restrictions of the LOO. Once these calculations are performed, the HLK/TGP/GBT Model follows the Columbia River TGP downstream accounting for the inflows from the Kootenay and Pend d'Oreilla River. To incorporate the operations of the ALGS with those of the HLK Dam, the past TGP analyses have mixed the discharges of the two facilities on a mass balance basis to arrive at the mixed Columbia River TGP.

In the past TGP studies, the analyses have been performed using daily average discharges for the facilities. A distribution formula developed by Klohn Crippen Integ was used to partition flows between the two facilities (J. Nunn personal communication). In more recent analyses of the proposed expansion to the Brilliant Dam on the Kootenay River the same methods were used for the HLK/ALGS operations and these were then combined with the altered operations of the Brilliant dam to arrive at a Columbia River TGP below the confluence of the Kootenay River and the Columbia River (Aspen Applied Sciences Ltd. 2001).

Mica WUP TGP Performance Measure Development

In early B.C. Hydro Mica WUP meetings in Castlegar B.C. (Westcott 2002), it was recognized that an improvement was needed in the earlier approach to TGP performance measures that used TGP alone. Specifically, these performance measures did not reflect the risk of GBT to fish for a given level of TGP or exposure duration. This was due in part to the lack of adequate GBT bioassay date at the time. Furthermore, the performance measures did not reflect the risk under conditions of dynamic exposure. That is, because the operations of the HLK Dam and ALGS Powerplant usually vary on a daily basis, and occasionally on an hourly basis, the TGP environment of the river changes accordingly. Thus, the exposure histories of fish to TGP become dynamic over time. Therefore, it was considered important that the Mica WUP TGP Performance Measures should reflect not only the risk of GBT to fish but if possible, the dynamic nature of the exposures. The situation involving dynamic TGP exposure is complicated further by fish behavior, as will be discussed in a later section.

In a separate study by Aspen Applied Sciences Ltd. (2002), it was established that comparative operational analyses performed under the Mica WUP should incorporate threshold TGPs as a part of the performance measure. This was important from the standpoint that there is likely a threshold TGP for the river environment below which there are no GBT impacts to fish. If TGP levels below the threshold are included in comparative operational analyses, they could easily distort analysis results that involve an integration of TGP risk over extended time periods (e.g. daily average values integrated over a one year period). Although the earlier study could not define a specific threshold based on river observations, laboratory data suggested a TGP value of 115%. The Columbia River data that do exist (Hildebrand 1991), suggested that TGPs as high as 120% may be tolerated by fish without acute or chronic effects. The two levels were recommended until further in-river studies can establish a specific threshold. It should be noted that the two thresholds were not related to the B.C. Guideline for Dissolved Gas Supersaturation (Fidler and Miller 1997). The thresholds were derived solely for comparing different HLK Dam operation scenarios under the WUP.

As described earlier, it was noted that TGP performance measures based on TGP alone do not reflect the actual risk to fish (i.e., based on TGP alone, the risk would rise linearly with TGP). On the other hand, laboratory data clearly illustrate that the risk rises non-linearly with TGP. For example, Figure 1 shows data from the literature that yield the time to 20% mortality for juvenile rainbow trout as a function of TGP. The data are from a number of literature sources, all for a temperature of 12 °C and for fish ranging in size from 100 to 150 mm in fork length. The exposures were steady state under shallow water laboratory conditions. Also shown in the figure is one of several analytic functions that provide a good representation of the data (r^2 > .95). Clearly, if time to 20% mortality is in any way related to GBT risk, the relationship is non-linear and hyperbolic in nature. No past studies have attempted to derive a measure of risk to fish from exposure to high TGP. For the Mica WUP studies it was decided to use the inverse of the time to 20% mortality function as a risk factor performance measure. Accordingly, taking the inverse of the analytic function of Figure 1 and introducing a constant factor to adjust the scale, Figure 2 yields a GBT risk factor for TGP that reflects the non-linear relationship between TGP and GBT risk. The scaling factor was chosen to yield a risk factor of 103 sec^{-1} for a TGP of 145%. Although the time unit of Figure 2 is hours, it can be transformed to days to yield a risk per day. When converted to inverse days, a slightly different scale factor would again yield a risk factor of 103 $days^{-1}$ at a TGP of 145%.

As can be seen in the figure, the risk factor for a TGP of 115% is quite low (0.38 $days^{-1}$), while that at a TGP of 145% is 103 $days^{-1}$. Thus, the risk per day of GBT exposure at a TGP of 145% is 271 times greater than it is at a TGP of 115%.

It should be noted that there are some limitations on the GBT risk factor performance measure. First, it is based on rainbow trout alone and may not necessarily represent all fish species in the Columbia River. At present there is no resolution to this limitation because there are very little data on time to 20% (or any other %) mortality on other Columbia River fish species.

Secondly, the risk factor is an indication of relative risk and not absolute risk. The reason for this is that the data upon which the risk factor is based (time to 20% mortality) are for fish exposed to TGP in shallow water laboratory environments. As explained in Weitkamp and Katz (1980) and in Fidler and Miller (1997), the water depth at which fish are exposed to elevated TGP has a major effect on their susceptibility to GBT. However, the water depth at which fish are exposed to TGP in the Columbia River is unknown. It varies with species, age class, river location, water temperature, diel conditions, season, weather, feeding opportunities, and a host of other factors (known and unknown) that are virtually impossible to quantify for any fish over an extended period (such as would be needed if it were to be pursued in the WUP). Consequently, the risk factor must be considered a relative risk factor and in no way reflects the absolute GBT threat to fish that any level of TGP may represent. However, this should be satisfactory for the Mica WUP comparative operations studies providing, as noted earlier, the threshold TGPs are incorporated into the analysis.

One further limitation exists as far as the risk factor relationship shown in Figure 2. The data from which the risk factor function is derived are for a water temperature of 12° C. Based on laboratory data from the literature (Nebeker et al. 1979), it is evident that there is a strong relationship between susceptibility to GBT and temperature for TGP levels that lead to mortality. Specifically, time to any level of mortality (e.g., 20%) decreases as temperature rises. Because the Columbia River water temperature varies with season, the risk factor relationship must be corrected to reflect the dependence of GBT risk on temperature. This was done using the data from Nebeker et al. (1979) that shows time to 20% mortality for steelhead trout over a range of temperatures and TGP. Figure 3 shows these data as a surface plot involving TGP, time to 20% mortality, and temperature. Initially, it was thought that this figure would provide a complete relationship for TGP, temperature, and time to 20% mortality that could form the basis for a GBT risk factor. Upon closer examination, it was found that the times to 20% mortality at the higher TGP were inconsistent with other data from the literature. This was due in part to attempting to fit a single surface to data that had significant scatter in some TGP/ temperature regions. However, it was observed that for any TGP, a polynomial relationship existed that related temperature to time to 20% mortality. Furthermore, it was discovered that the polynomial was the same for all TGPs when normalized to a temperature of 12° C. This then allowed the creation of a correction factor that could be applied to the analytic relationship of Figure 2 for risk factor. The polynomial correction factor is shown in Figure 4. Thus, the final relationship for the GBT risk factor that incorporated TGP, temperature, and time to 20% mortality was a product of the risk factor function of Figure 2 and the temperature correction polynomial of Figure 4. This preserved the higher accuracy of the data from Figure 1 and the temperature dependence of GBT mortality and temperature. The Relative Risk Factor equation is shown below.

RRF=250/(*(c_+a*TT+b*TT^2)/((aaa+ccc*TGP)/(1+bbb*TGP))^2)

Where: RRF = Relative Risk Factor
TT = Temperature in °C
TGP = Total Gas Pressure in % of saturation.

250 = Scaling factor

and,

aaa	-0.48176
bbb	-0.008847
ccc	0.0002881
C	1.2167
a	0.0078
b	-0.0022

TGP Production by the HLK Dam

One further component was needed before the Mica WUP TGP performance measures could be applied to different operational scenarios for the HLK Dam. It was necessary to use the HLK/TGP/GBT computer model to predict HLK TGP levels. In past analyses (Aspen Applied Sciences Ltd. 1997, 1998, 2001), the program was run for each daily average discharge condition. This involved many weeks of computational effort in order to cover the years of operation that were examined in the analyses (usually 10 years). In order to avoid this extended effort, a new approach was taken. It was observed that the current HLK LOO restricted dam operations to the extent that for any given discharge and total head across the dam, there was a unique configuration of spillway and low level port openings that led to a minimum TGP. It was further recognized that rather than run the program for each daily discharge condition that might be considered in WUP comparative operational analysis, it was possible to run the program for a range of total heads and discharges which would allow the creation of a table of corresponding TGPs. If the increments of head and discharge were fine enough, a single lookup table could be created in Microsoft Excel that could then be used for all of the comparative operations analyses that might be considered in the Mica WUP. In other words, a week to ten days of effort could replace many weeks of work. The lookup table was created by Aspen Applied Sciences Ltd. and incorporated into two TGP – risk factor spreadsheets for B.C. Hydro. The two spreadsheets reflected the two threshold TGPs of 115% and 120%. The spreadsheets allow the operations of the HLK Dam alone and the combined operations of the HLK Dam and ALGS Powerplant to be analyzed for any discharge conditions on any time scale (e.g., daily, weekly, or monthly average discharge conditions). Columbia River TGPs were predicted and the corresponding GBT relative risk factors calculated. The original spreadsheets were designed using daily average discharge conditions from previous analyses (Aspen Applied Sciences Ltd. 1997, 1998, 2001). The risk factor columns were summed over the yearly operations to give a single yearly relative risk factor. This cumulative relative risk factor could then be used for comparing different yearly operational scenarios (e.g., different yearly hydrographs). These spreadsheets [identified as HLK-ALGS WUP PERFORMANCE MEASURE (115%) and HLK-ALGS WUP PERFORMANCE MEASURE (120%)] were transmitted to B.C. Hydro in October 2002.

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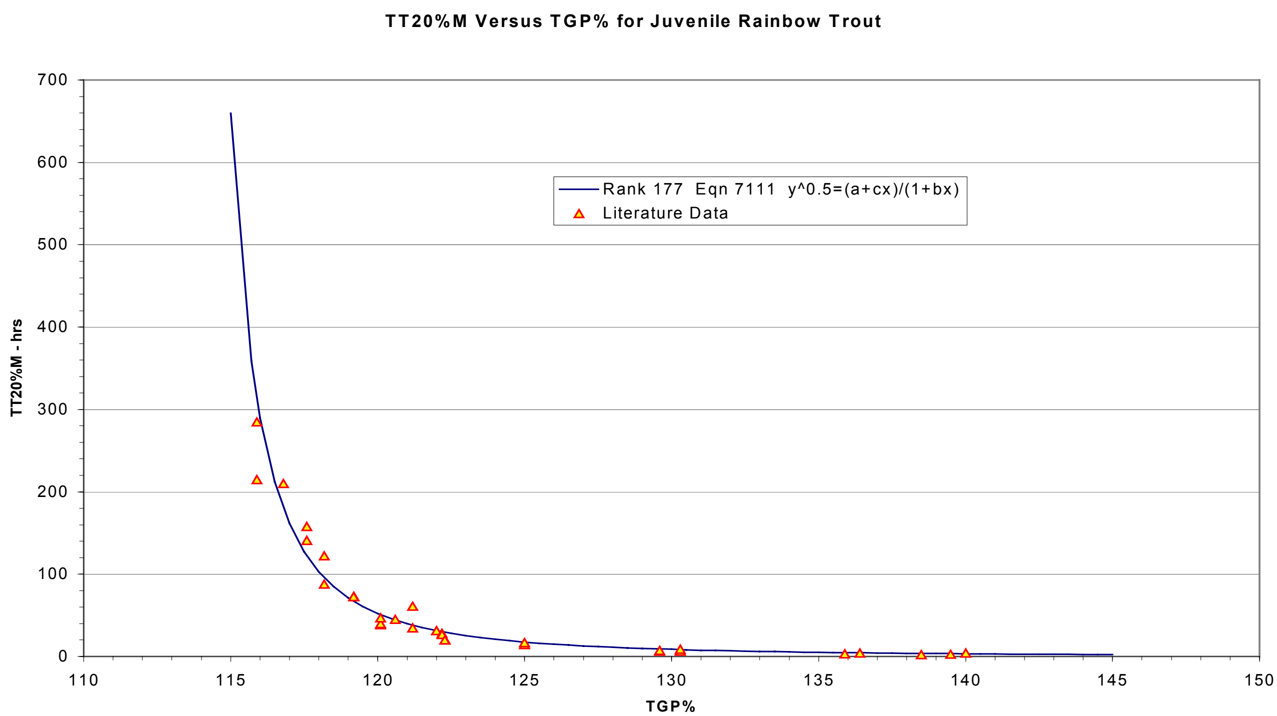

Figure 1: Time to 20% Mortality for Rainbow Trout as a Function of TGP.

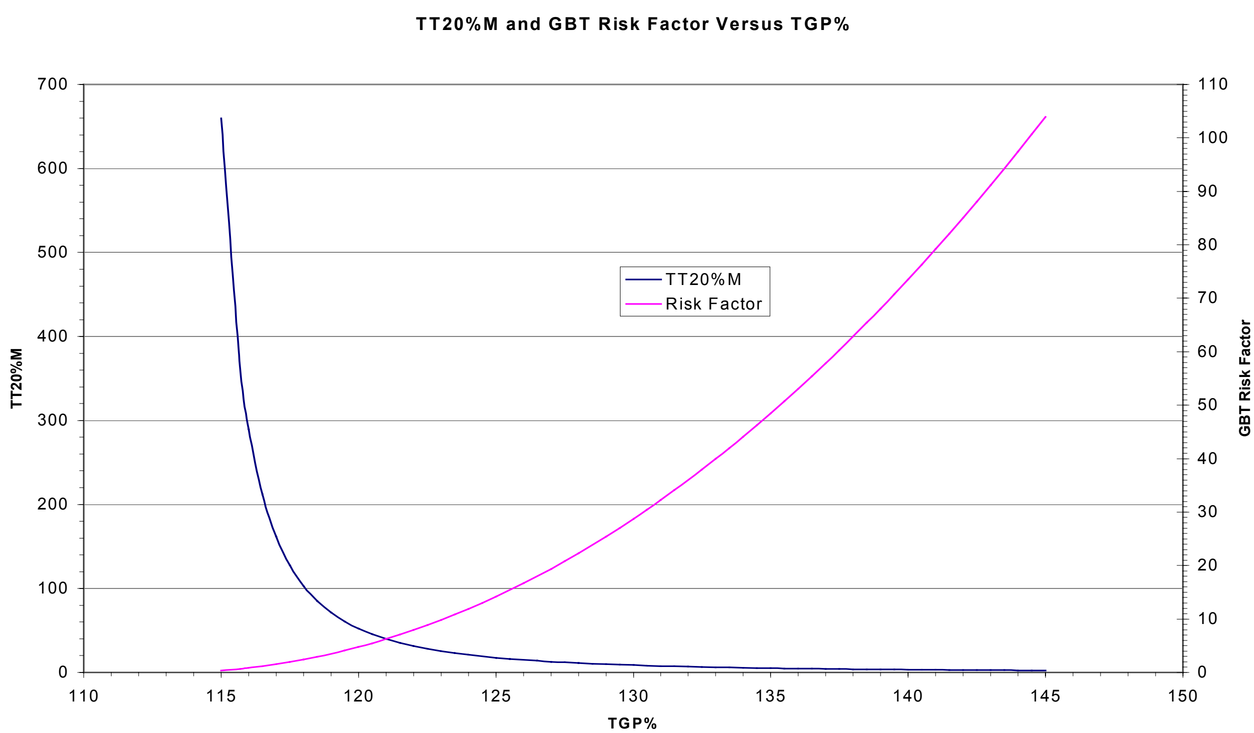

Figure 2: Time to 20% Mortality and GBT Risk Factor as a Function of GBT

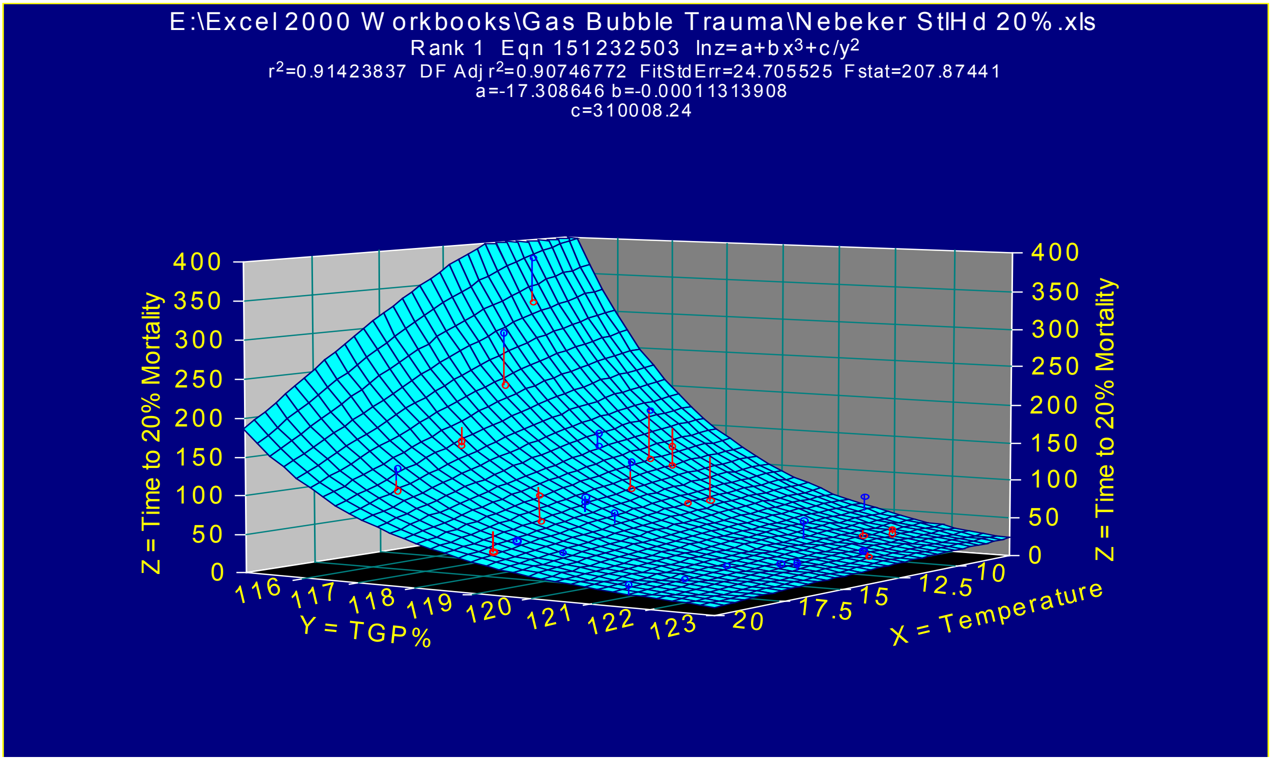

Figure 3: TGP, Temperature, and Time to 20% Mortality from Nebeker et al. 1979.

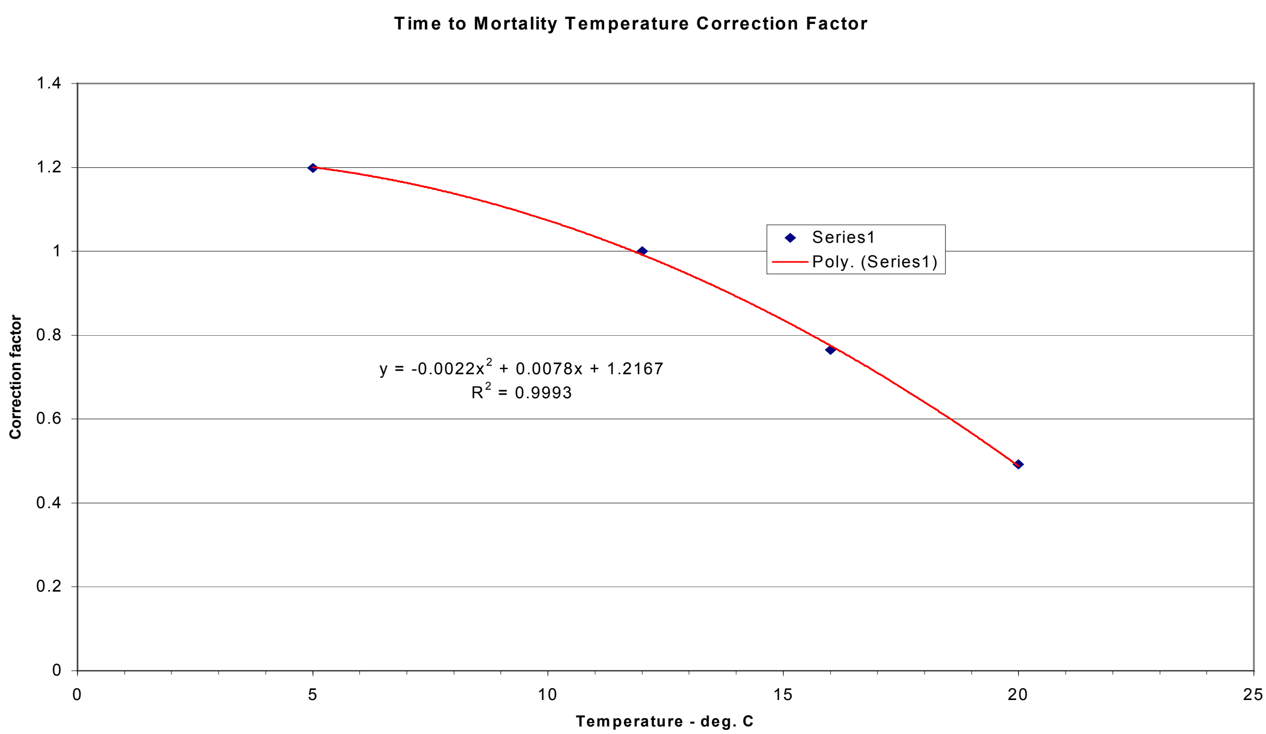

Figure 4: Temperature correction factor.